Dc machines

I. Theoritical questions

Q1: Draw the Construction of a Dc machine showing its components.

Q2: What is the role of Commutator & brushes in Dc machines.

Q3: Derive the emf equation (E_a) in Dc machines

Q4: Show the relation between θ_e & θ_p, then, Derive an expression relating the frequency (f_e) to the mechanical speed(n

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Q5: Show flux distribution in Dc machines.

Q6: Describe the operation of Dc machine as a generator & as a motor

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Q7 : Draw the circuit diagram of Dc generators, then show why the external c/c's of shunt Dc generator is more drooping than separately excited.

Q8 : Draw the circuit diagram of various types of Dc motors.

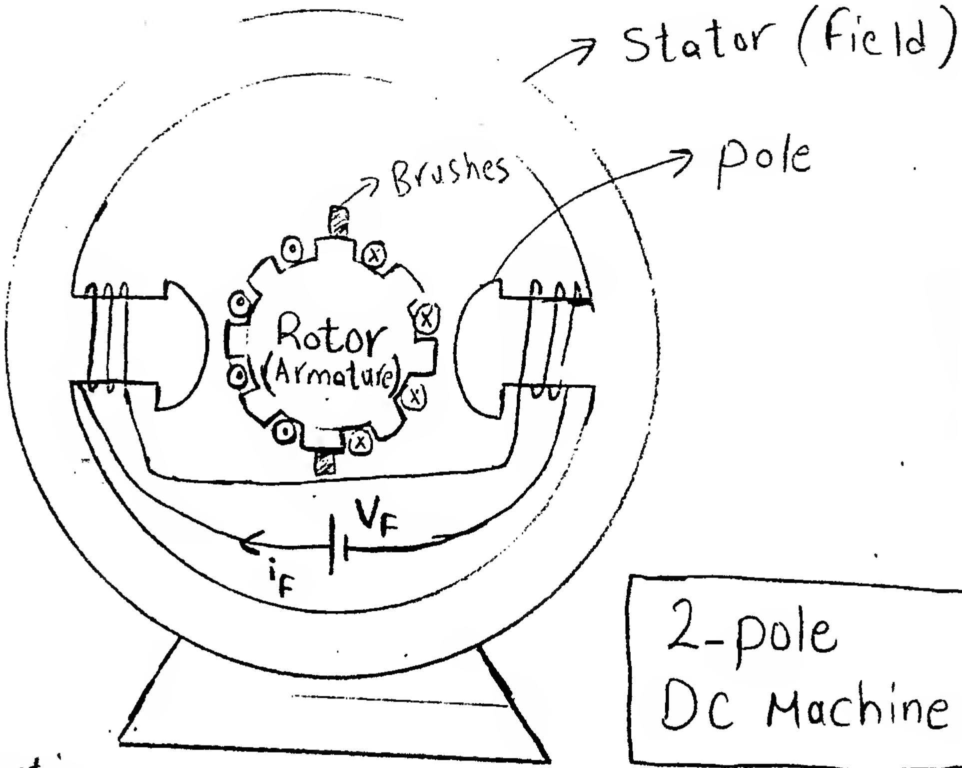
Q9 : What is the signifance (role) of back emf in Dc machines.

Q10 : Why is the starting current is high in Dc machines, How to limit this current.

③

Answer of Q1

Dc Machines



2-pole
Dc Machine

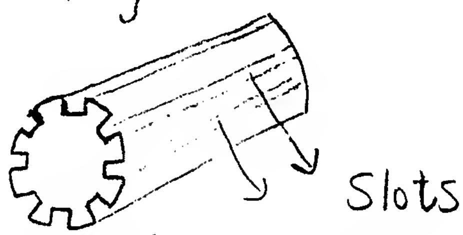
Construction

① Stator

- Carries the field winding (exciter)
- Field winding is connected to Dc Voltage source
- Field winding produces the magnetic flux.

2 Rotor

- Carries armature winding
- Rotor has a cylindrical shape with slots
- The conductors are placed in these slots.
- e.m.f is induced on the terminals of armature winding.



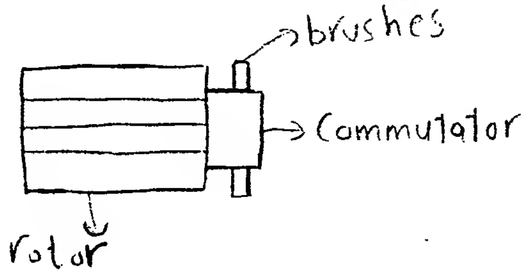
- Rotor is laminated to reduce eddy losses.

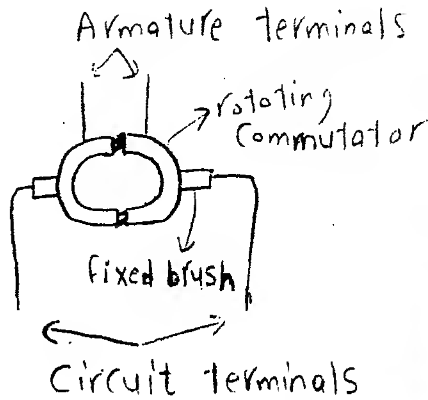
3 Commutator

* It's a copper cylinder divided into isolated segments
* It's connected to armature winding terminals
* It's a rotating part.

4 Carbon brushes

- They are fixed Contacts
- They are in direct Contact with the Commutator





5 Air gap:

- It's the Clearance between Stator and rotor

Answer of Q_2

Notes

(a) Commutator is used to
- → convert AC Voltage to DC Voltage in case of DC genartor
- → produce unidirectional torque in DC motor

(b) The horizontal axis is called pole axis,
The Vertical axis is called interpole axis.

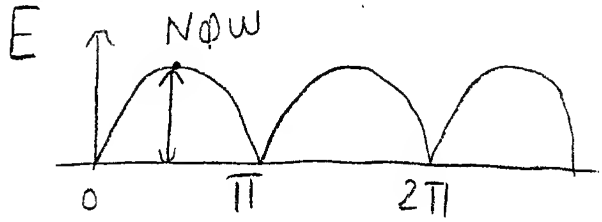
Answer of Q3

The flux linkage of armature conductor:

$$\lambda = N\Phi \cos \omega t$$

but $e_i = \frac{-d\lambda}{dt} = +N\Phi\omega \sin \omega t$

* The commutator produces DC Voltage



$$\therefore E_a = \frac{2N\Phi\omega}{\pi}$$

E_a ↓ average armature Voltage

$$\therefore E_a = Kn\Phi$$

$E_a \propto n\Phi$

But $\Phi \propto I_f$

$\therefore E_a \propto n I_f$

→ If $I_f = 0 \Rightarrow E_a = 0$

→ If $n = 0 \Rightarrow E_a = 0$

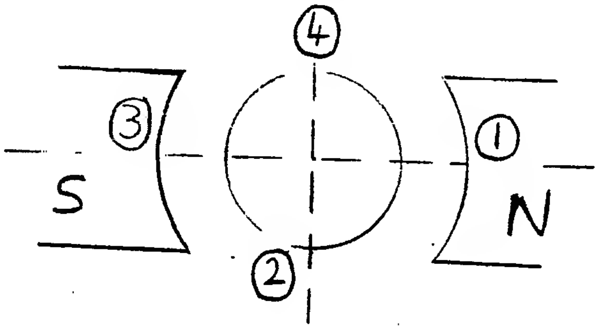
Answer of Q4

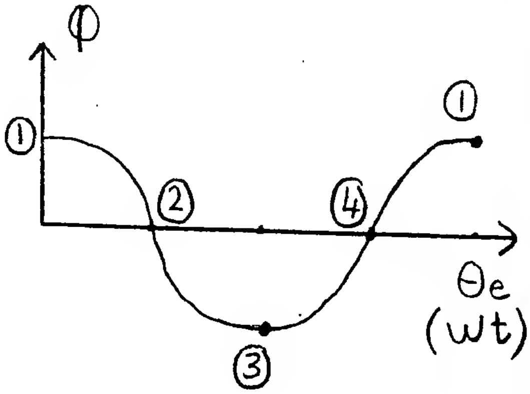
Relation between θ_e, θ_m

$\theta_e = \omega t$; ω is electrical angular frequency

$\theta_m = \omega_m t$; ω_m is mechanical angular frequency

For 2 poles ($P = 1$) no. of pole pair





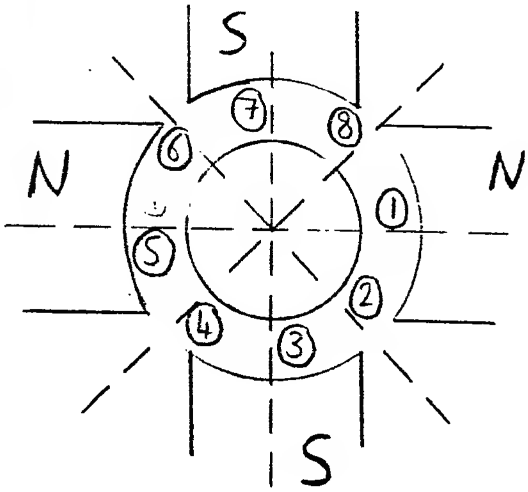
1 → 2 $\theta_m = 90°$ $\theta_e = 90°$

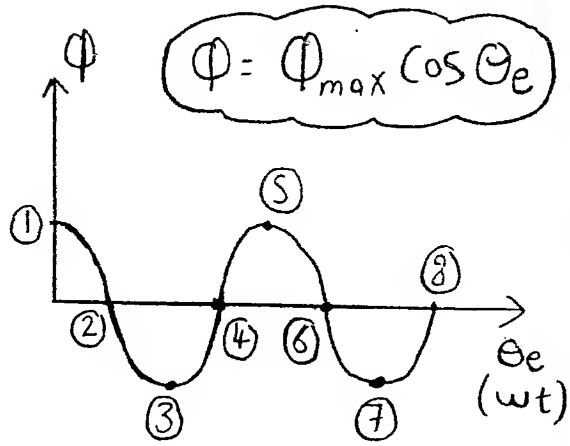
2 → 3 $\theta_m = 90$ $\theta_e = 90$

$$\boxed{\therefore \theta_m = \theta_e}$$

For 2 poles

For 4 poles $(p=2)$





$① \rightarrow ②$ $\theta_m = 45$ but $\theta_e = 90$

$② \rightarrow ③$ $\theta_m = 45$ but $\theta_e = 90$

$\therefore \boxed{\theta_e = 2\theta_m}$

∴ For (p) poles

$$\theta_e = p \times \theta_m$$

$$\therefore \omega_e = p\,\omega_m$$

حفظ

- When $p=1 \Rightarrow \theta_e = \theta_m$, $\omega_e = \omega_m$
- When $p=2 \Rightarrow \theta_e = 2\theta_m$, $\omega_e = 2\omega_m$

Relation between f_e & n_m

$\because \theta_e = p\,\theta_m$

$$\therefore \frac{d\theta_e}{dt} = p\,\frac{d\theta_m}{dt}$$

$$\omega_e = p\,\omega_m$$

$$\therefore 2\pi f_e = p * 2\pi f_m$$

$$\therefore f_e = p\,f_m$$

But $f_m = \dfrac{n}{60}$

where n: Number of revolutions per minute (rpm)

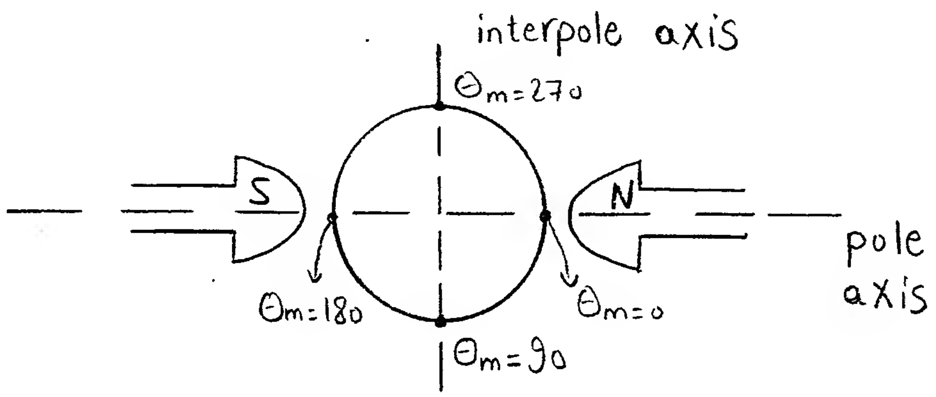
$$\therefore \boxed{f_e = \frac{pn}{60}}$$

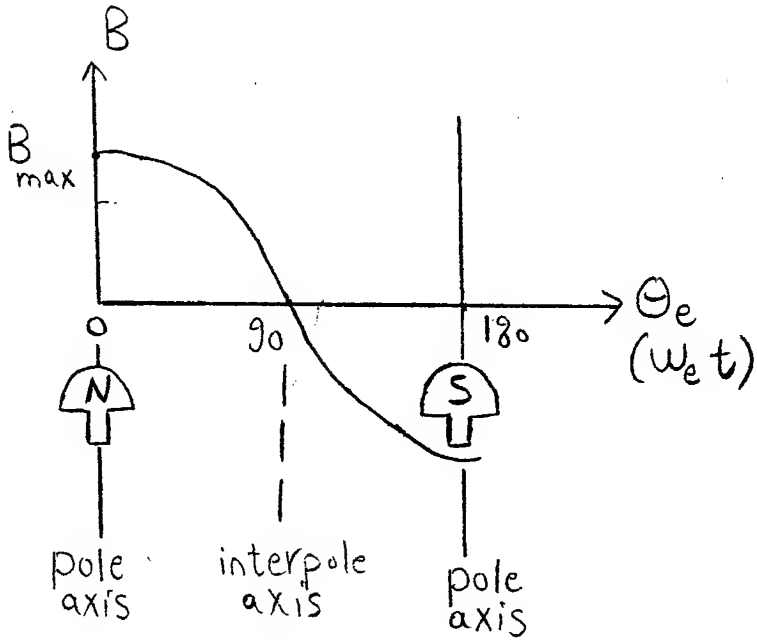
f_e: electrical frequency (HZ)

p: Number of pole pairs

n: Mechanical speed of rotor in rpm

Flux denisty distribution in DC machine [Flux of stator]





$\therefore B = B_{max} \cos(\omega_e t)$

This means that the Flux Varies sinusoidal

Dc machine can operate as

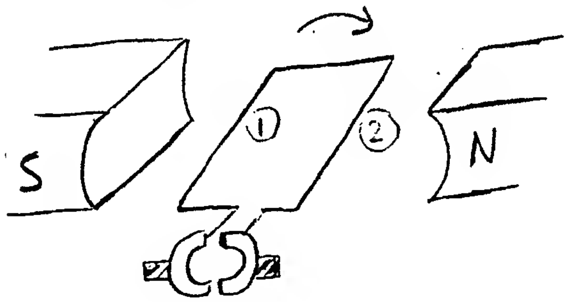
① Dc generator
② Dc motor

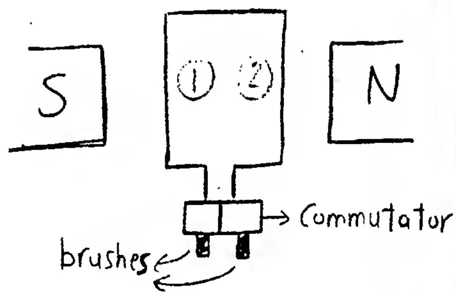
1 DC generator

Theory of operation

ⓐ The field current produces Flux

ⓑ If the rotor (armature Coil) is externally rotated

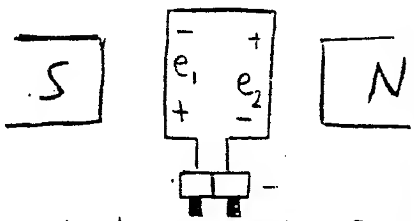




ⓒ A Voltage will be induced on both Conductors (1,2)

$e_1 = BLV$ $\quad e_2 = BLV$

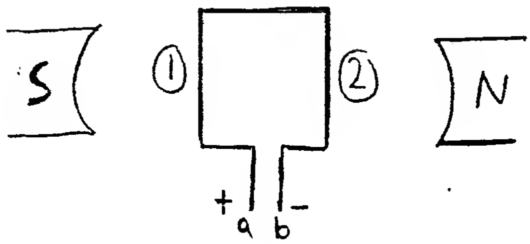
$e_{coil} = 2BLV$



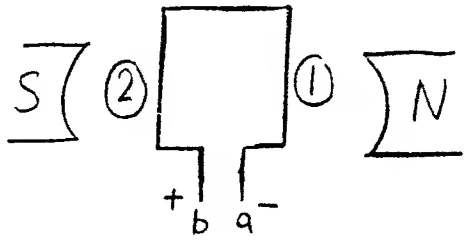
ⓓ The Commutator Converts Ac Voltage into Dc.

Why do we use Commutotor & brushes

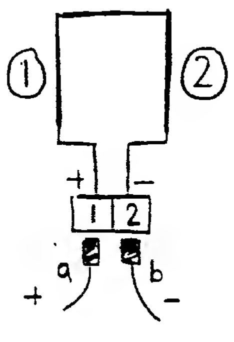
In First half Cycle of the Coil rotation

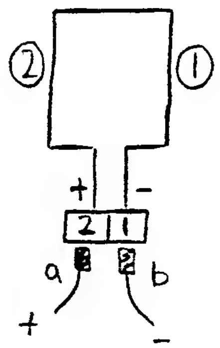


In Second half Cycle of the Coil rotation



The Voltage across the coil changes its polarity, So we use Commutator and brushes as a mechanical rectification to get DC Voltage from the Coil





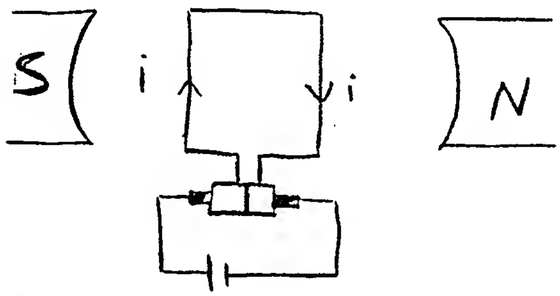
* brush ⓐ is +ve in both half cycles
  brush ⓑ is −ve 〃 〃 〃 〃

2 DC motor

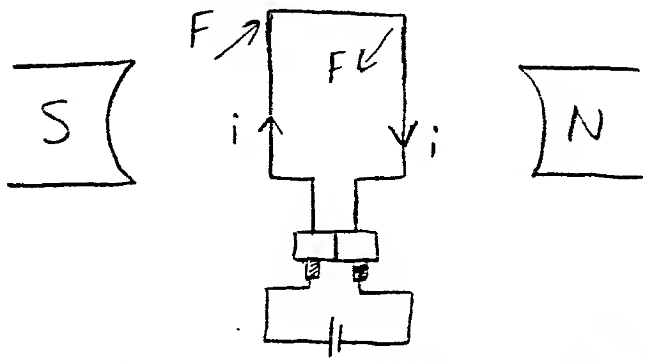
Theory of operation

(a) The field current produces flux

(b) If the armature winding terminals are connected to an external DC source, then a current will flow in armature winding.



(c) Now both conductors (1,2) has a current i and placed in a magnetic field (B), so a force will be produced on both conductors but in opposite direction. ($F=BIL$)



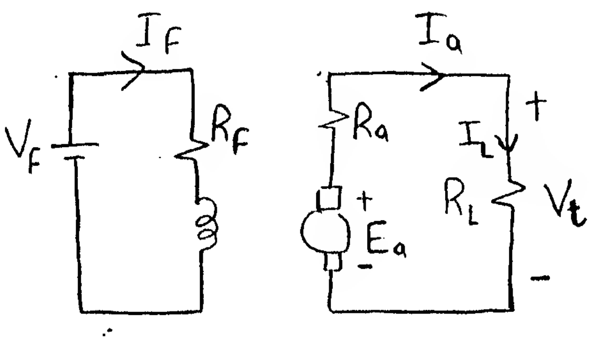
ⓓ So, the Coil Starts to rotate with a torque $T = BILW$

ⓔ As the Coil rotates in a magnetic field, so a back emf will be induced on the Coil (as in generator)

ⓕ The Commutator converts the torque into unidirectional torque

Types of DC generators

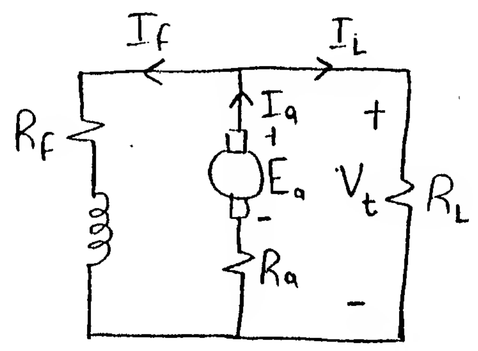
I Separately excited



$V_f = I_f R_f$

$E_a = V_t + I_a R_a$

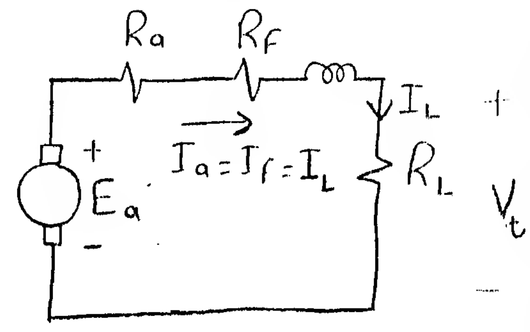
II Shunt



$I_f = \frac{V_t}{R_f}$

$E_a = V_t + I_a R_a$

III Series

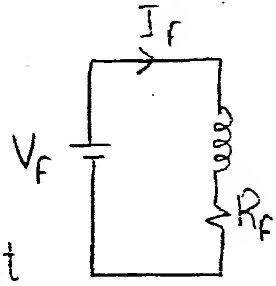


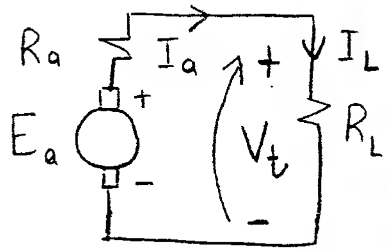
$E_a = V_t + I_a (R_a + R_f)$

$I_a = I_L = I_f$

I Separately excited DC generator

⇒ Field circuit





$$V_f = I_f R_f$$

* I_f → field current
* R_f → field resistance

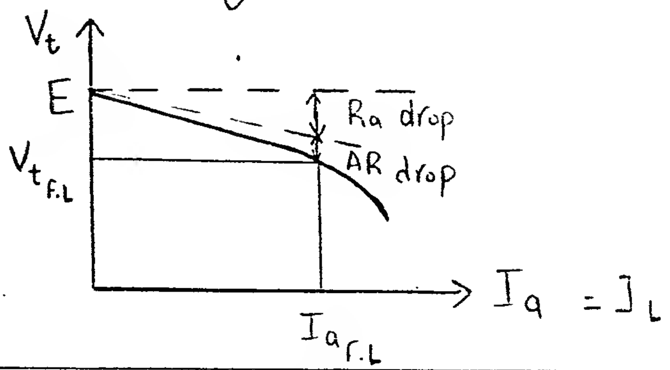
⇒ Armature circuit

$$E_a = V_t + I_a R_a + (\text{Armature reaction drop})$$

* R_a → Armature resistance
* I_a → Armature current
* V_t → Terminal Voltage

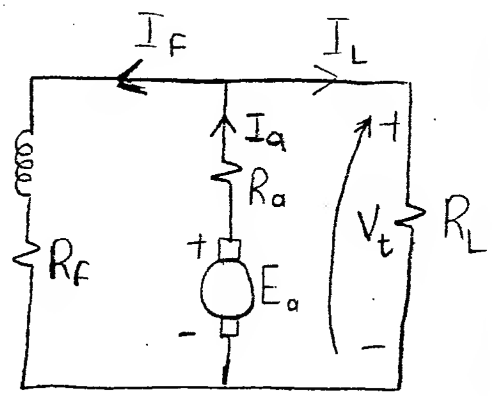
IF (AR) is neglected ⇒ $E_a = V_t + I_a R_a$

⇒ External characteristic of separately excited DC generator



II Shunt DC generator

$$I_f = \frac{V_t}{R_f}$$



$$E_a = V_t + I_a R_a$$

The Voltage drop is due to

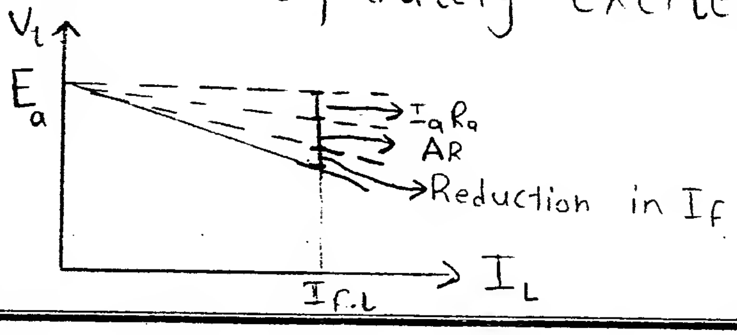
1. R_a drop.
2. Armature reaction drop
3. Decrease in field current

as $I_f = \dfrac{V_t \downarrow}{R_f}$ (V_t decrease as I_L increases)

$\therefore I_f \downarrow \rightarrow \Phi \downarrow \rightarrow (E_a = Kn\Phi) \downarrow \rightarrow V_t \downarrow$

That's why shunt DC generator has external C/C's which is more drooping than that of separately excited (عشان Sep.excited بيحصله اول نوعين من ال drop فقط)

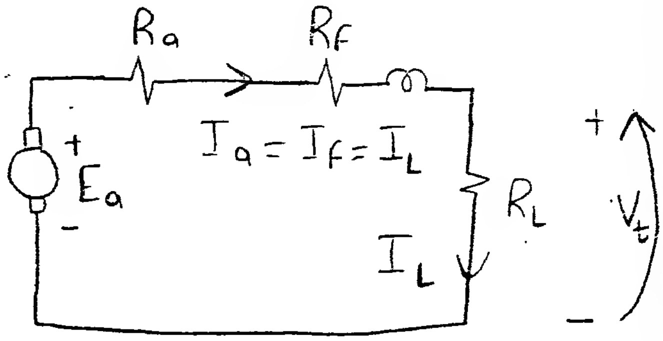
External C/C's



III Series DC generator

$I_a = I_f = I_L$

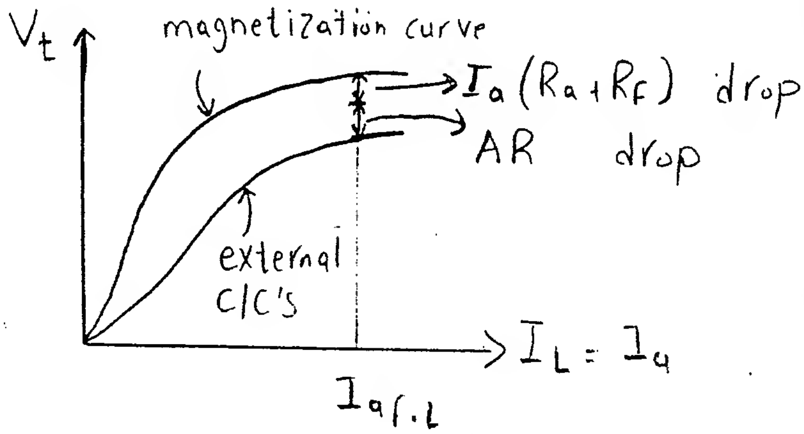
$E_a = V_t + I_a(R_a + R_f)$



The Voltage drop is due to

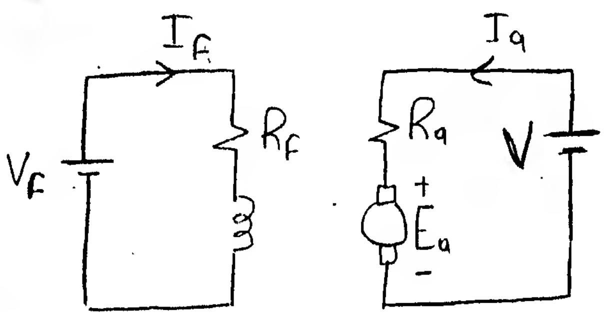
1. $(I_a R_a + I_a R_f)$ drop
2. AR drop

External C/C's



Types of Dc motors

I Separately excited

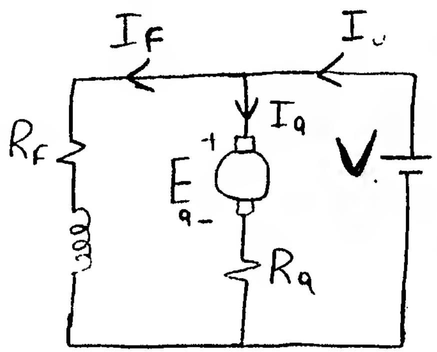


$V_f = I_f R_f$ $\quad$ $E_a = V - I_a R_a$

$E_a = K n \Phi \Rightarrow E_a \propto n I_f$

$T = K I_a \Phi \Rightarrow T \propto I_a I_f$

II Shunt

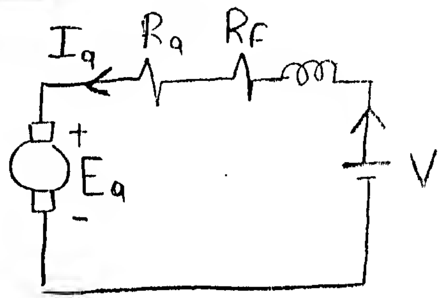


$I_f = \frac{V}{R_f}$ $\quad$ $E_a = V - I_a R_a$

$E_a = K n \Phi \Rightarrow E_a \propto n I_f$

$T = K I_a \Phi \Rightarrow T \propto I_a I_f$

III Series



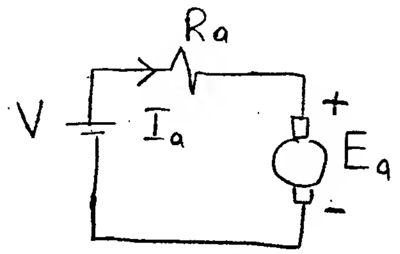
$E_a = V - I_a (R_a + R_f)$

$E_a = K n \Phi \Rightarrow E_a \propto n I_a$
$E_a \propto n I_f$

$T = K \Phi I_a \Rightarrow T \propto I_a^2$

Role of back emf (E_a) in motors

E_a produces a current opposite to the supply current, so the armature current is limited within acceptable range



Starting of DC motors ⟹ Answer of Q10

$\because V = E_a + I_a R_a$

$\therefore I_a = \dfrac{V - E_a}{R_a}$ but $E_a = K n \phi$

But at starting $(n=0) \Rightarrow E_a = 0$

$\therefore I_a\big|_{St.} = \dfrac{V-0}{R_a} \uparrow\uparrow$ (Very high)

$\therefore$ The armature current is very high at starting, so we must use starters (Starting resistors to reduce $I_a|_{st.}$)

II- problems

Laws

1. $\underset{\text{rad/s}}{\omega} = \dfrac{2\pi n}{60}$ $n \rightarrow$ rpm

2. $E = K\phi\omega \rightarrow$ (a)

   But $\phi \propto I_f$, $\omega \propto n$

   $E = K_1 \phi \cdot n \rightarrow$ (b)

   $E = K_2 I_f n \rightarrow$ (c)

3. $T = K \phi I_a \rightarrow$ (a)

   $T = K' I_f I_a \rightarrow$ (b)

   $T_d = \dfrac{P_d}{\omega} \rightarrow$ (c) (T_d: developed torque)

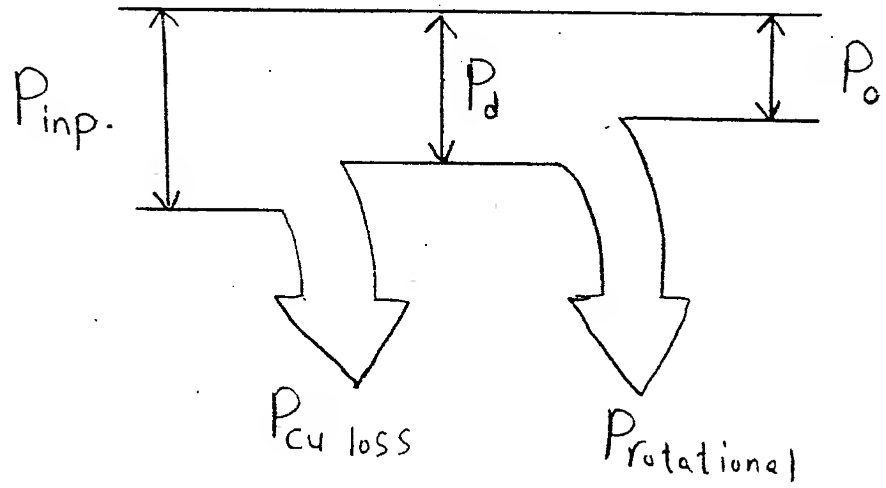
4. $T_o = \dfrac{P_o}{\omega}$ (T_o: output or shaft torque)

   $P_o = P_d - P_{friction}$

5. If $E > V_t \longrightarrow$ generator

   If $E < V_t \longrightarrow$ motor

power flow in DC motor



* $P_{inp} \equiv$ input power $= V_s I_{inp.}$ → input current

* $P_{cu_{loss}} = I^2 R$ (depends on connection)

* $P_d \equiv$ developed power $= E_a I_a = T_d \, \omega_m$

* $P_r \equiv$ rotational loss

* $P_o \equiv$ output power $= T_{sh} * \omega_m$
  (T_{sh} → Shaft torque)

$$\eta = \frac{P_o}{P_{inp.}} = \frac{P_{inp} - \sum losses}{P_{in}}$$

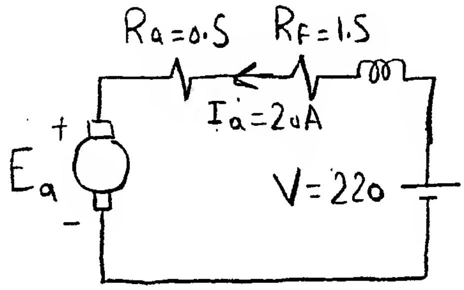
* $P_o = P_d - P_{rotational}$ * $P_d = P_{in} - P_{cu_{loss}}$

(14) sheet Series motor

- $R_a = 0.5\,\Omega$, $R_F = 1.5\,\Omega$
- $I_a = 20\,A$ when $n = 1200\,rpm$
- $V = 220\,V$, $P_{rotational} = 150\,W$

Find P_o, η

Solution



$E_a = V - I_a(R_a + R_F)$

$E_a = 220 - 20(0.5 + 1.5)$

$\therefore E_a = 180V$

$\Longrightarrow P_o = P_d - P_{rot.}$; $P_d = E_a I_a = 3600\,W$

$\therefore P_o = 3600 - 150$

$P_o = 3450\,W$

$\Longrightarrow P_i = V * I_a = 4400$

$\Longrightarrow \eta = \frac{P_o}{P_i} = \frac{3450}{4400} = 78.4\%$

$\eta = 78.4\%$

15 Sheet

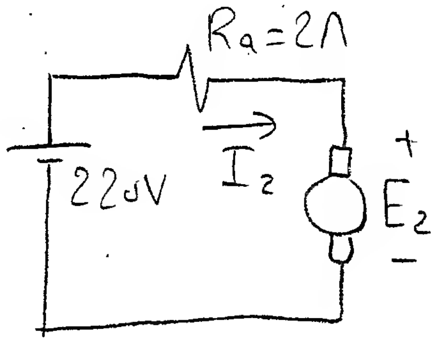
- DC motor (Assume separately excited)
- at No load: $V = 100V$; $n = 1200rpm$
- $R_a = 2\Omega$
- Find T, I_a if $V = 220V$, $n = 1500 rpm$
- I_f is Constant

Solution

Case 1: $V = 100V$, $n_1 = 1200rpm$, No load $(I_a \simeq 0)$

$E_1 = 100V$

Case 2: $V = 220V$, $n_2 = 1500rpm$



$$* \quad \frac{E_2}{E_1} = \frac{n_2}{n_1}$$

$$\frac{E_2}{100} = \frac{1500}{1200} \Rightarrow E_2 = 125$$

$$* \quad E_2 = 220 - 2I_2 \Rightarrow I_2 = 47.5$$

$$* \quad P_d = E_2 I_2 = 5937.5W$$

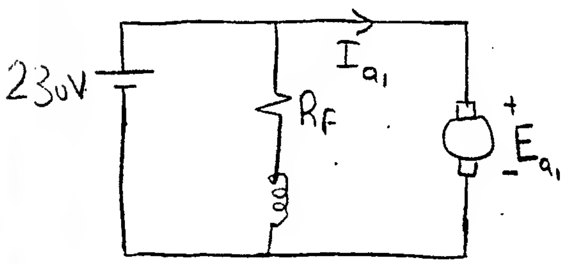
$$* \quad T_d = \frac{P_d}{\omega} = \frac{5937.5}{2\pi\left(\frac{1500}{60}\right)}$$

$T_d = 37.8 \, N.m$

(16) sheet
- DC Shunt motor
- Constant field ($I_f = \text{Const.}$)
- $T \propto n$
- $I_a = 30A$ when $n_1 = 750$ rpm
- $R_{series} = 10\Omega \Longrightarrow n_2 = ??$
- R_a is neglected

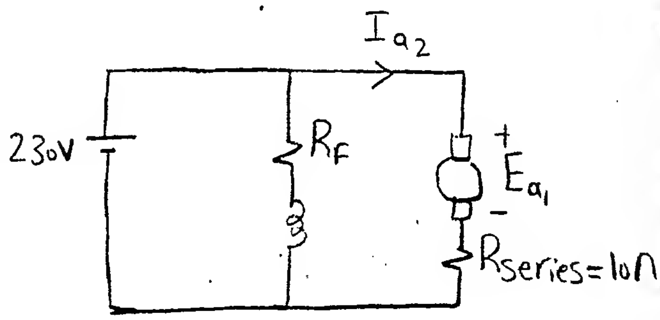
Solution

Case (1) $n_1 = 750$ rpm
$I_{a_1} = 30A$



$E_{a_1} = 230V$

Case (2) $R_{series} = 10\Omega$



$E_{a_2} = 230 - 10 I_{a_2}$

$\Longrightarrow$ But $E \propto n\underset{\text{Constant}}{\phi} \Longrightarrow E \propto n$

$$\therefore \frac{E_2}{E_1} = \frac{n_2}{n_1}$$

$$\frac{230 - 10 I_2}{230} = \frac{n_2}{750}$$

$$0.306\, N_2 + 10\, I_2 = 230 \quad \rightarrow (1)$$

$\Rightarrow$ But $T \propto n$ (given)

$$T \propto \underbrace{\phi}_{\text{const.}} I_a \Rightarrow T \propto I_a$$

$$\therefore \frac{T_2}{T_1} = \frac{n_2}{n_1} = \frac{I_2}{I_1}$$

$$\therefore \frac{n_2}{750} = \frac{I_2}{30}$$

$$\therefore n_2 = 25\, I_2 \quad \rightarrow (2)$$

Solving (1), (2) we get

$$I_{a_2} = 13\,A$$

$$n_2 = 325.7 \text{ rpm}$$